Leave No Trace!.... ....In the Sky

Aviation Contrails

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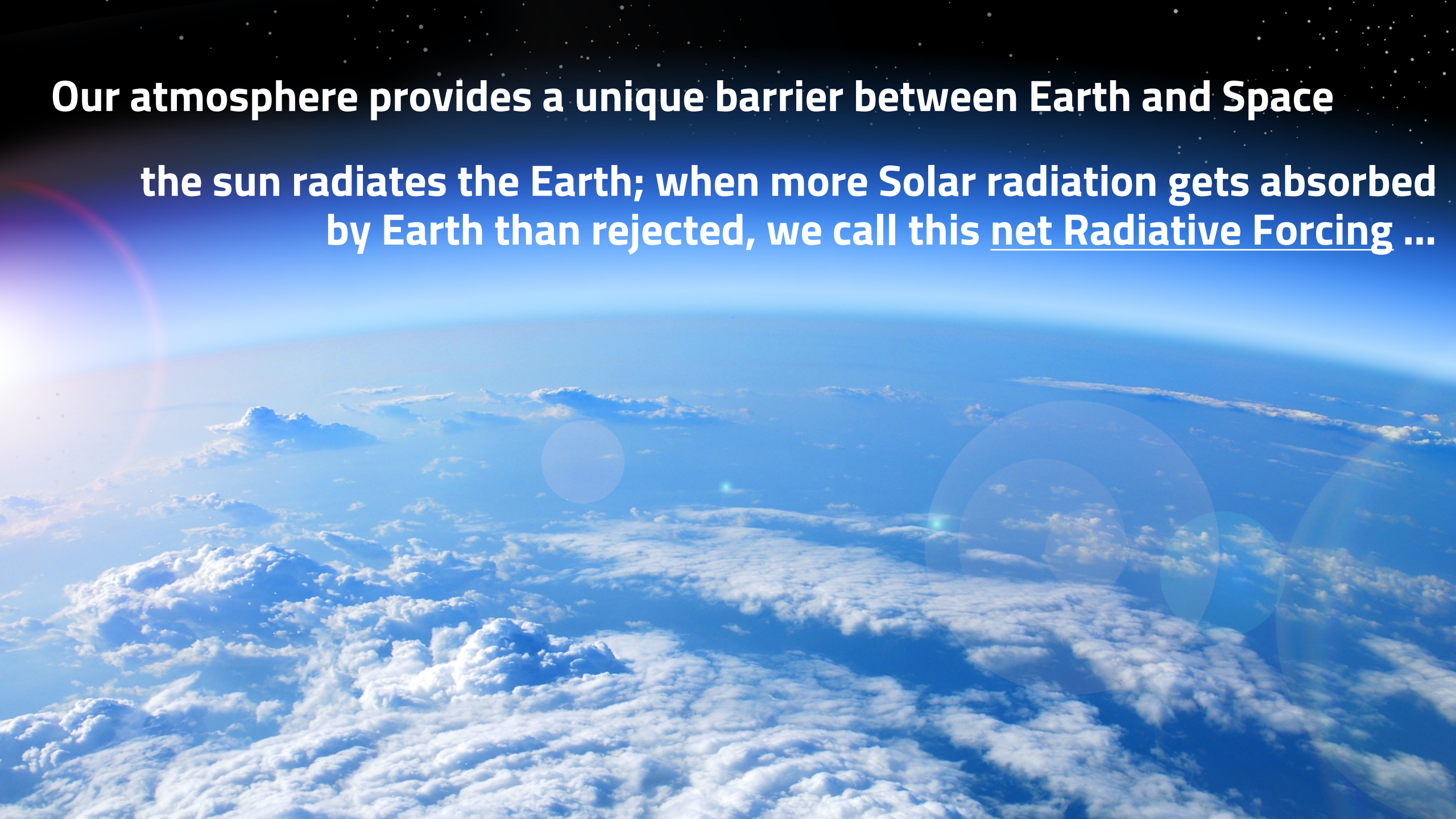
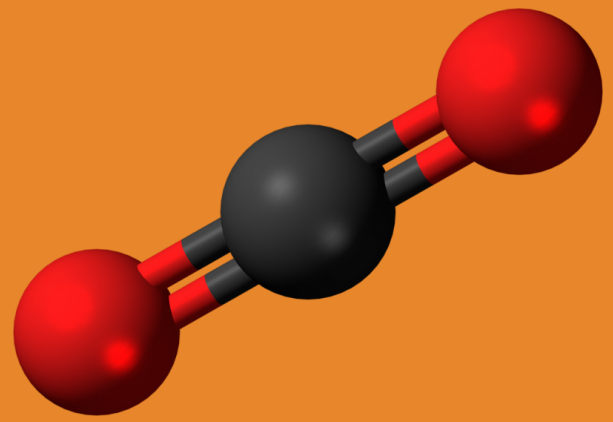
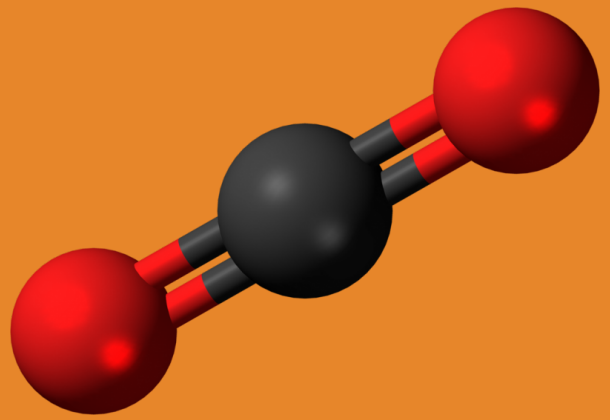

Our atmosphere provides a unique barrier between Earth and Space
the sun radiates the Earth; when more Solar radiation gets absorbed by Earth than rejected, we call this net Radiative Forcing ...

Carbon Dioxide CO_2



2% created by Aviation
Radiative Forcing ~34 mW/m²
(long term greenhouse gas)

Carbon Dioxide CO_2



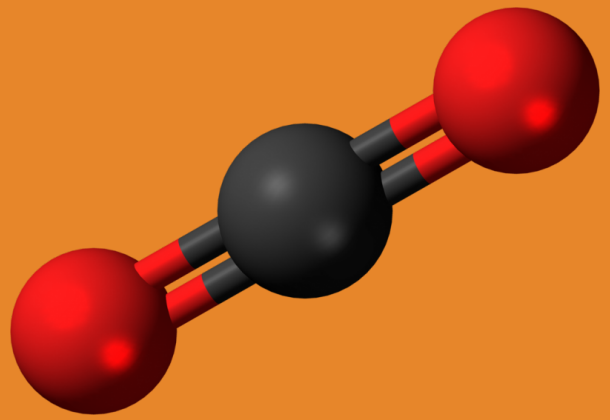
2% created by Aviation
Radiative Forcing ~34 mW/m²
(long term greenhouse gas)

Water Vapor H_2O

(Contrail Ice Crystals at high altitudes)

Lee, D.S., Fahey, D.W., Skowron, A., Allen, M.R., Burkhardt, U., Chen, Q., Doherty, S.J., Freeman, S., Forster, P.M., Fuglestvedt, J. and Gettelman, A., 2021. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, *244*, p.117834.

Carbon Dioxide CO_2



2% created by Aviation
Radiative Forcing ~34 mW/m²
(long term greenhouse gas)

Water Vapor H_2O

(Contrail Ice Crystals at high altitudes)

Radiative Forcing ~57±40 mW/m²
(short term greenhouse gas)

Lee, D.S., Fahey, D.W., Skowron, A., Allen, M.R., Burkhardt, U., Chen, Q., Doherty, S.J., Freeman, S., Forster, P.M., Fuglestvedt, J. and Gettelman, A., 2021. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, *244*, p.117834.

- Contrails are trails of frozen water vapor, ice crystals that form behind engines at high altitudes
- Future aircraft will operate on a combination of battery and sustainable aviation fuel solutions. New “greener” fuels have the potential to produce more water vapor
- Depending on the atmospheric conditions contrails can disperse rapidly, or freeze and create persistent contrail cirrus clouds, which can be barriers for heat leaving earth

Contrails are a challenging Scientific problem

Contrails occur when a combination of atmospheric conditions and jet engine parameters align

Boeing 787 in flight, no contrails

Source: Boeing

Boeing 787 at high altitude– big contrails but are they persistent or dissipate?

Source: Youtube - LouB747 - RARE Contrails | Early morning 787 Dreamliner

Mean contrail coverage from 1 January 2018 to 31 December 2019

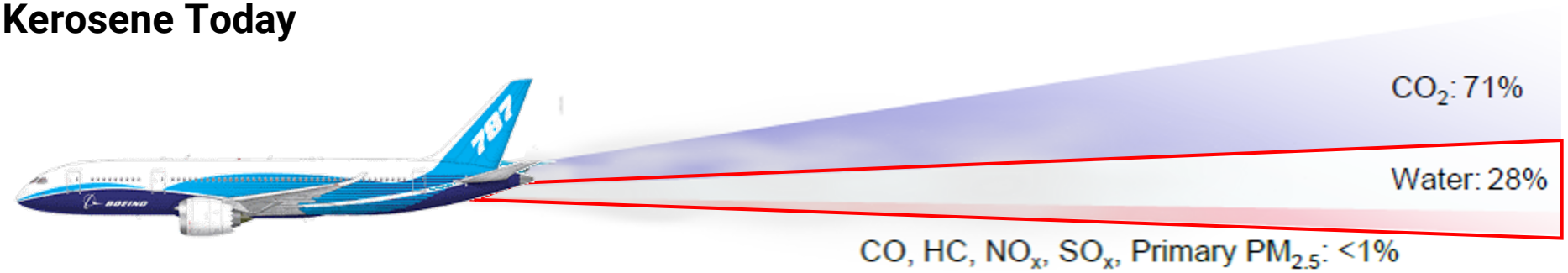
Meijer, V.R., Kulik, L., Eastham, S.D., Allroggen, F., Speth, R.L., Karaman, S. and Barrett, S.R., 2022. Contrail coverage over the United States before and during the COVID-19 pandemic. *Environmental Research Letters*, *17*(3), p.034039.

Contrails are significant now, could be more in future

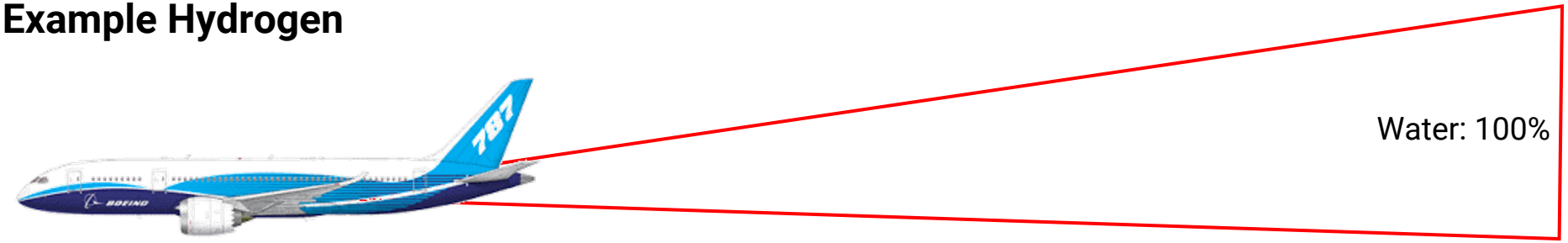
Acknowledgements: Dr. Miad Yazdani

Atmospheric conditions, combustion byproducts and water are factors for contrail formation

Kerosene Today



Example Hydrogen



Contrail factors:
- More water
+ No combustion byproducts?

We need to understand contrail formation, the atmospheric conditions under which they might pose a challenge and explore technologies to mitigate them

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CHANGING WHAT'S POSSIBLE

Vision: Can an airplane “detect” it is producing persistent Radiative Forcing (RF) contrails and technology be developed to “live” mitigate it

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Step 1: Trustworthy “live” AI Contrail Predictor

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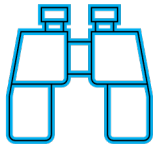
Objective: find minimal sensor suite for 99% confidence in persistent contrail prediction

Step 2: Active Contrail mitigation Technology

Sensor Technology needs arpa·e



Forward sensors

- Humidity Sensor @10 km, 10^{-5} -10^{-4} kg/kg
- Ambient particulates/other?

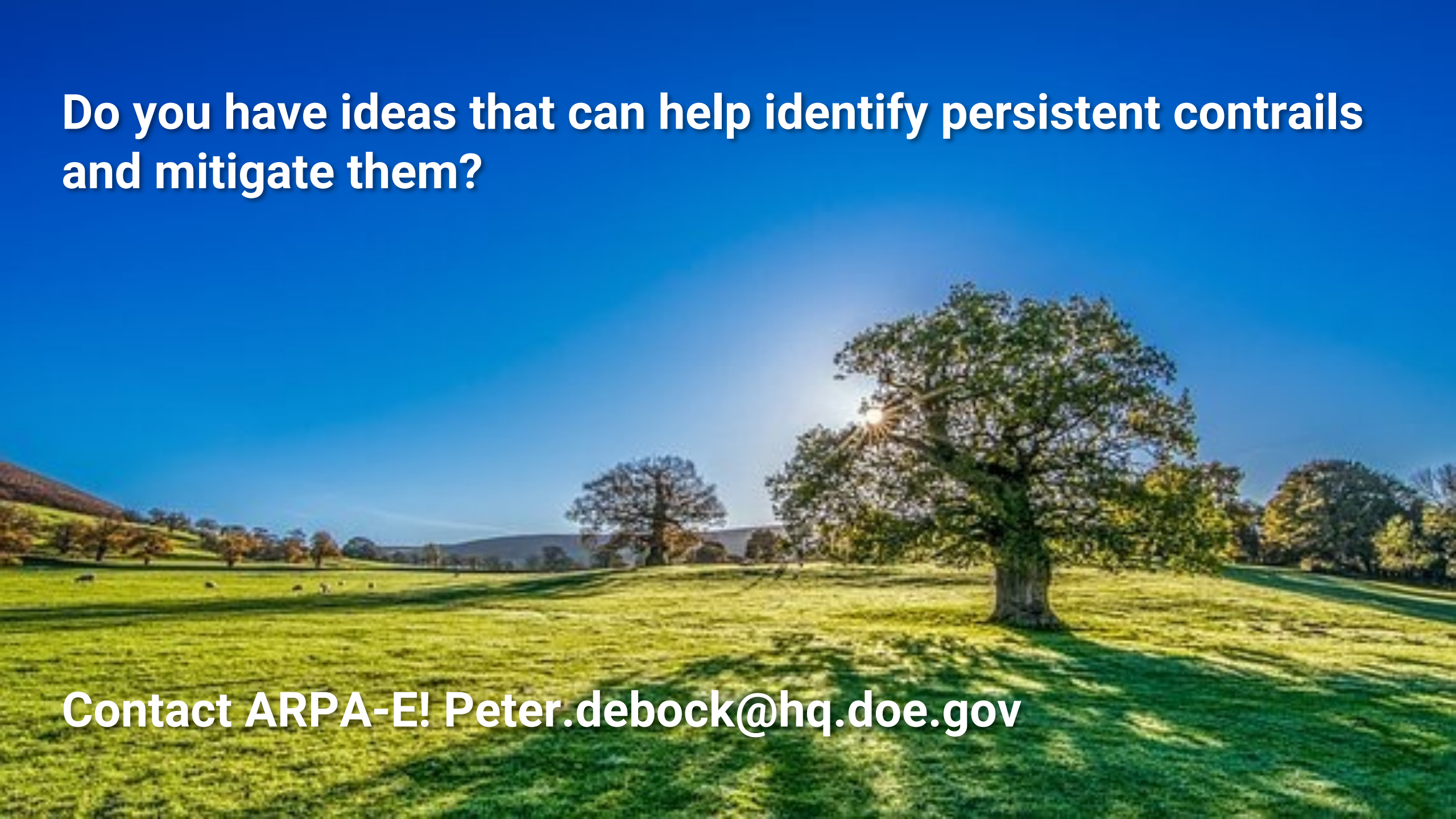
Contrail persistency sensor network

- Airborne sensor: On airplane forward/backwards + weather balloon/satellite?
- Ground based: Camera observer network

Combine with flight plan & other data sources

- Flight path
- Location, time
- Weather data
- Solar radiation angle
- Aircraft type and model
- Fuel type

Acknowledgements: Steven Barrett, Sebastian Eastman, MIT


Do you have ideas that can help identify persistent contrails and mitigate them?
Contact ARPA-E! Peter.debock@hq.doe.gov